

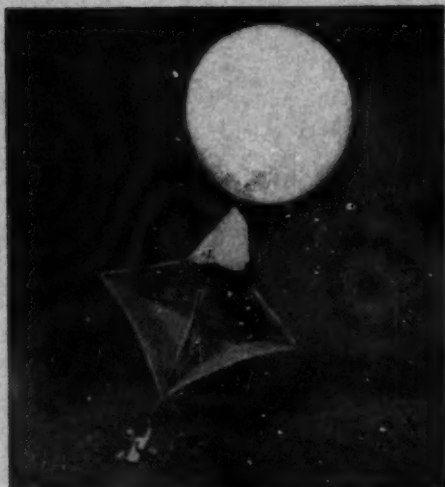
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meteorological  
magazine***

JULY 1964 No 1104 Vol 93

Her Majesty's Stationery Office



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# THE METEOROLOGICAL MAGAZINE

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## FLUORESCENT PARTICLES AND THEIR USE IN STUDYING AIR MOTION

By N. THOMPSON

**Summary.**—Experiments are described in which fluorescent particles of zinc cadmium sulphide were released from an aircraft and used as a 'tracer' to measure vertical diffusion. An apparent loss of these particles with increasing time of travel was noted and further studies showed that the main cause of this loss was a decrease in the fluorescent efficiency of the particles after exposure to daylight.

**Introduction.**—Many meteorological investigations entail tracking parcels of air, often with the aid of balloons or by means of air-mass characteristics and synoptic charts. But a more direct method of tracking is to label an air parcel by injecting into it a suitable tracer material. One such material is zinc cadmium sulphide<sup>1,2</sup> in the form of fluorescent particles and it is usually referred to as F.P. The material is finely ground, with particles mainly in the size range between 1 and  $5\mu$  ( $1\mu = 10^{-4}$  cm); it fluoresces brightly with a characteristic yellow colour when illuminated with ultra-violet light, and is also manufactured in forms that fluoresce red or green. The material is usually released into the atmosphere after being fed into a strong air blast which breaks up aggregates of the particles, and is sampled either by drawing the air containing it through very fine filters, or by impacting it onto treated surfaces. Under ultra-violet light, the particles can be counted through a relatively low-powered microscope magnifying 80 to 100 times. Concentrations lower than 10 particles per cubic metre can be measured by these techniques. Each gram of F.P. contains about  $10^{10}$  particles, and with suitable source strengths the material is satisfactory for diffusion experiments over distances ranging from a few metres to 100 km or more. This article discusses a few of the meteorological experiments carried out with F.P. in this country. Initially, these were to study vertical diffusion, but some of the later investigations were concerned with aspects of the tracer technique.

**Some measurement of vertical diffusion.**—In experiments carried out to study vertical diffusion over distances of travel up to 130 km, the particles were released as a line source from an aircraft flying across wind, and were collected by sampling instruments mounted at heights of up to 6000 ft on the cable of a single captive balloon (see Plate I). These instruments were drum impactors, mounted on units containing pumps operated by light-weight batteries. The units were controlled from the ground, with provision for switching the pumps on and off, and also for rotating the drums through small angles to expose a succession of fresh sampling surfaces. Some of the results

are shown diagrammatically in Figures 1(a) and 1(b), where the numbers of particles collected have been plotted against sampling height for 8 experiments. Three of the experiments (numbers 4, 5 and 6) were over relatively short distances (mean travel 16 km), but the remainder involved travel of about 130 km. The diagrams reveal a combination of comparatively rapid diffusion at lower levels (e.g. experiments 4 and 5), with much slower, or negligible, diffusion in the vicinity of temperature inversions. For example, in experiment 1 where conditions were unstable, particles had failed to diffuse to 5000 ft even after travelling about 130 km although the inversion base lay less than 1000 ft below this level. In experiment 2 a very strong subsidence inversion (8°C) was present between 6000 and 6500 ft and the F.P., released several hours before in convective conditions, reached 6000 ft in only small numbers.

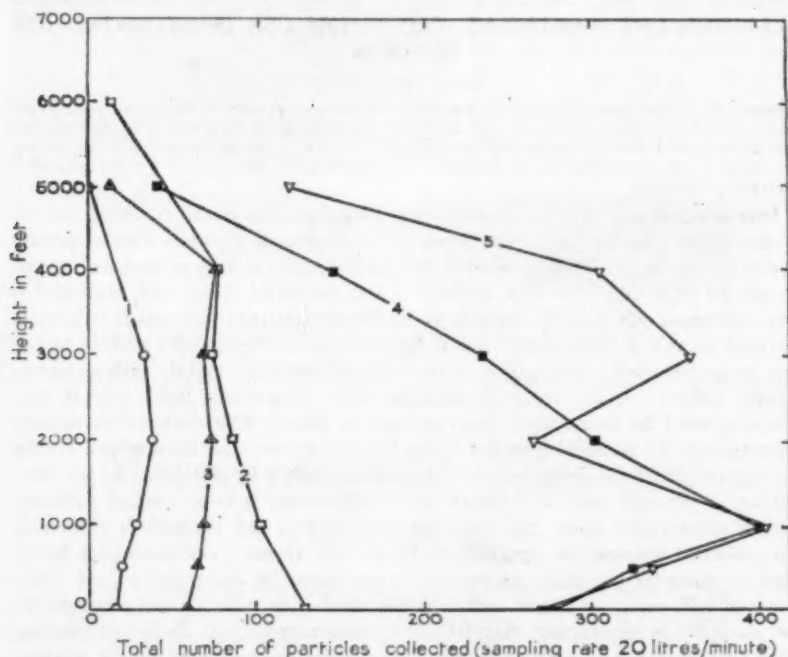


FIGURE 1(a)—PARTICLE COLLECTION PROFILES, 1959

Experiment number	Release height feet	Distance of travel kilometres	Approximate inversion height feet	Amount	Cloud Type	Base feet
1	1000	126	4500	1/8	Ac	15,000
2	1000	135	6500	1-3/8	CuSc	3500-4500
				7/8	Sc	5000-6500
3	1000	129	5500	1-6/8	Sc	3800-4000
4	1000	16	5500	1/8	Cu	4500
				5-7/8	Sc	5000
5	1000	16	5500	3-6/8	Ac	9000-12,000

The layer below the inversion was unstable in experiment 1 and slightly unstable in experiments 2-5.

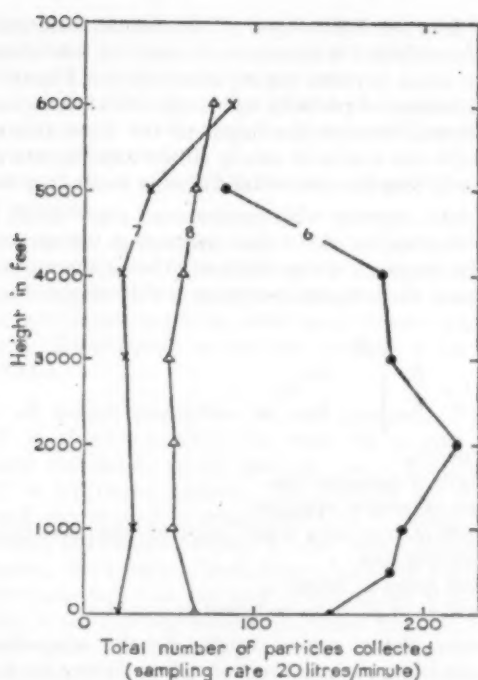


FIGURE 1(b)—PARTICLE COLLECTION PROFILES, 1960

Experiment number	Release height feet	Distance of travel kilometres	Approximate inversion height feet	Amount	Cloud Type	Base feet
6	2000	15	7000	2-4/8	CuSc	6000
				1-4/8	Ac	10,000
7	5500	129	7500	1-4/8	Cu	3500 bec. 4000
				6-7/8	Sc	5000 bec. 7000
8	3750	118	7500	1-5/8	Cu	3500-5000
				4-7/8	Sc	7000

The layer below the inversion was slightly unstable in experiments 6-8.

Similar results were found from experiment 3. All demonstrated that upward transfer was slow in the vicinity of inversions, and experiment 7, with its higher-level release (5500 ft) also showed this slow transfer, since a marked peak persisted at about the release level after several hours' travel. Generally, F.P. released several thousand feet below the marked temperature inversion became more or less uniformly distributed in the convectively turbulent layer below the inversion after a very few tens of kilometres travel.

Vertical turbulence (i.e. the standard deviation of the wind inclination to the horizontal) was measured in all experiments by vanes attached to the balloon cable<sup>a</sup> and records obtained from vanes within the inversions always showed low values of turbulence. The assumption often made that these subsidence inversions act as barriers to vertical diffusion therefore seems justified for periods of travel of at least a few hours.

**An apparent loss of F.P.**—One of the factors determining the total number of particles collected is the source strength or rate of emission of F.P. This did not vary much between the experiments, but Figures 1(a) and 1(b) show that larger numbers of particles were collected at short ranges. This was somewhat unexpected, because the depth of the layer through which the particles were mixed was similar in nearly all the experiments, and the source lines were sufficiently long for cross-wind diffusion to produce no dilution.

The sampling data, together with simultaneous observations of wind speed from airmeters attached to the vanes measuring turbulence enabled the quantity called the 'recovery' to be deduced. This is the number of airborne particles carried past the samplers per gram of F.P. originally emitted and is given by

$$\Omega = \frac{D}{m} \int_0^H \frac{Un}{s} dz,$$

where  $\Omega$  = recovery,

$D$  = length of emission line,

$m$  = mass of powder released,

$H$  = depth of layer over which particles were distributed,

$s$  = sampling rate,

$U$  = wind speed at height  $z$ ,

$n$  = number of particles collected at height  $z$ .

Values of  $Un/s$  were plotted against height and the integration carried out graphically. In some cases, the particles had diffused above the highest sampler, and it was necessary to extrapolate before performing the integration. For this reason the recoveries obtained from experiments 7 and 8, with about 125 km of travel, were more uncertain than the others. Occasionally the effective source strength was increased or decreased by confluent or diffluent airflow and a correction was applied for this. The results appear in Table I.

TABLE I—PARTICLE RECOVERIES

Experiment number	Distance of travel kilometres	Mean times of travel hours	Recovery particles per gram $\times 10^{10}$
1	126	6.0	0.32
2	135	5.6	0.91
3	129	4.2	0.97
7	129	3.5	1.12
8	118	5.3	0.84
Means for experiments 1,2,3,7,8	127	4.9	0.83
4	16	1.5	1.97
5	16	1.5	2.64
6	15	0.8	1.40
Means for experiments 4,5,6	16	1.3	2.00

A  $t$ -test showed the differences of mean long-range and short-range recoveries to be highly significant ( $> 0.1$  per cent level).

The plausible reasons for this apparent loss of F.P. with increasing travel were considered to be:

- (i) A redistribution of particles in the atmosphere, e.g. by penetration of the temperature inversion or by cross-wind diffusion, or diffuence.
- (ii) Deposition of the particles on the ground.
- (iii) A decrease in the efficiency of the tracer with increasing time of exposure to the atmosphere, for example by chemical decomposition or by loss of fluorescent brightness.
- (iv) Deficiencies of the tracer technique, for example in sampling or assessment of samples.

A more detailed study showed item (i) to be relatively unimportant; the effect of diffuence was allowed for as far as possible in computing the recoveries, and penetration of inversions was soon rejected since experimental results, including some not mentioned here, have never shown this to occur to any significant degree. Experiments to test the validity of the remaining items are described below.

**Deposition of small particles on the ground.**—The mean settling velocity of F.P. is about 0.1. cm/s, but near the ground this is effectively increased because the inertia of the particles will allow them to impact on vertical as well as horizontal surfaces. The particles are therefore deposited onto surfaces and objects such as grass, trees and buildings. The particles are normally uniformly distributed through a layer much deeper than the height of these roughnesses, and continual turbulent mixing will maintain this approximate uniformity provided that the rate of deposition is small. Under these conditions, there is an approximately exponential decrease in the number of airborne particles with increasing distances of travel. The rate of deposition is conveniently expressed in terms of the 'deposition velocity,' which is the downward velocity that the particles very near the ground must have to produce the observed deposition. This rate of deposition per unit area is given by the deposition velocity multiplied by the particle concentration. The mean recoveries at the two distances (Table I) imply a deposition velocity of about 10 cm/s, provided that this is the only way in which the F.P. is being lost. This is much greater than a value (0.25 cm/s) found from experiments on the deposition of radio-actively tagged F.P. onto grass in a wind tunnel.<sup>4</sup> This latter estimate may not be a good one for field deposition because of the different wind profile near the ground, and deposition on trees and buildings and other large surface roughnesses might be larger.

**An attempt to estimate deposition of F.P. on trees.**—It is not practicable to use a microscope to make quantitative estimates of the deposition of F.P. on foliage. There is a simple alternative which proved to be sufficiently accurate for the present purpose. Suppose the wind direction is perpendicular to a long belt of trees of similar height. Slightly in front of the trees the mean airflow is horizontal, but nearer the belt, a proportion of the airflow is deflected upwards. Of the air actually entering the trees, a proportion passes upward through the tree tops during the passage through the belt and the remainder passes out on the downward side. An experiment was carried out to measure these proportions for an airflow past a belt of trees about 60 m deep and 12 m high. About 15 per cent of the air was deflected over the trees on the upwind side and another 50 per cent passed upwards through the tree tops instead of flowing through the trees. While these observations were obtained, a number of cross-wind line releases of F.P. were made about 1 km upwind of the trees

and were sampled by arrays of drum impactors, upwind and downwind of the belt. The numbers of particles passing through vertical sections upwind and downwind of the belt were found, and compared with the corresponding airflows. The observations showed a rather wide scatter but suggested that total deposition was very small. A tentative upper limit for this, used in conjunction with an estimate of tree cover over the area involved in the large-scale vertical diffusion measurements, was only sufficient to explain less than 10 per cent of the loss in these experiments.

**The size distribution of F.P.**—Some studies of the size distributions of collected particles confirmed that deposition was not the major cause of the F.P. loss. Large particles are more likely to be deposited on obstacles than small particles. Suppose, for example, particles of two sizes,  $1\mu$  and  $4\mu$ , are carried by a 5 m/s airflow past a cylinder of 0.1 cm diameter mounted with the axis perpendicular to the flow. The cylinder would collect about 50 per cent of the  $4\mu$  particles but scarcely any of the smaller ones. Deposition would therefore result in a gradual decrease in the relative numbers of the large particles. There was an indication in earlier work that the reverse was occurring. A series of specially designed experiments, involving the sampling of cross-wind line releases of F.P. by cascade impactors at distances up to 80 km, was carried out to confirm this. This kind of impactor splits up the sample into four slightly overlapping size ranges and is, therefore, a very convenient apparatus for measuring particle size. The sizing characteristics differ slightly between impactors, and to reduce uncertainties of interpretation, six or eight were used at each of three positions, at about 15, 40 and 80 km downwind of the line source. The glass slides on which the particles are impacted, were changed at the same time interval at all stations (quarter-hourly or half-hourly). The amounts of atmospheric pollution impacted on the slides were therefore kept reasonably small. Assessment was by techniques similar to those used for the drum-impactor samples. Table II gives the results from two experiments carried out during daylight hours.

TABLE II—DAY-TIME SIZE-DISTRIBUTION EXPERIMENTS

Experiment Number	Distance of travel kilometres	Period of travel hours	Mean percentage of particles collected by impactor stages			
			Stage 1	Stage 2	Stage 3	Stage 4
1	14	0.6	1.4	24.5	62.0	12.1
	39	1.3	3.5	35.7	58.9	1.8
	73	2.2	8.0	42.0	49.4	0.6
2	13	0.5	1.7	27.0	66.1	5.1
	39	0.9	3.2	29.8	63.7	3.4
	76	1.6	8.6	46.5	44.6	0.3

Diameters of particles collected are  $>8\mu$  in stage 1;  $3-8\mu$  in stage 2;  $1-3\mu$  in stage 3; and  $<1\mu$  in stage 4.

The percentage of particles collected by the fourth stages of the impactors decreased quickly with time of travel to insignificant values after about 2 hours, implying an almost complete disappearance of particles of less than about  $1\mu$  diameter. There was also a systematic decrease in the proportion of particles collected by the third stages (roughly between  $1\mu$  and  $3\mu$  diameter). Assuming that none of the particles normally collected by the second stages of the impactors were lost by deposition, each experiment suggested about a 40 per cent decrease in recovery between the extreme sampling positions. An unexplained feature was that the systematic increase in the proportion of particles collected by stage one was too large to be accounted for by loss of particles normally collected by stages three and four.

The results from one experiment carried out at night appear in Table III.

TABLE III—NIGHT-TIME SIZE-DISTRIBUTION EXPERIMENT

Distance of travel kilometres	Period of travel hours	Mean percentage of particles collected by impactor stages			
		Stage 1	Stage 2	Stage 3	Stage 4
16	1.8	0.6	21.2	60.9	17.2
40	2.8	0.2	27.3	63.0	9.5
80	3.9	1.8	31.5	58.4	8.3

Diameters of particles collected are  $>8\mu$  in stage 1;  $3-8\mu$  in stage 2;  $1-3\mu$  in stage 3; and  $<1\mu$  in stage 4.

It is seen that the decrease in the proportion of small particles was much less pronounced than in the day-time experiments, in spite of the longer periods of travel involved. This suggests that the apparent loss of particles might in part be due to some sort of chemical decomposition in daylight, or to progressive loss of ability to fluoresce under ultra-violet light.

**Measurement of fluorescent brightness.**—Another investigation has now shown that the fluorescent brightness of the small particles of the particular types of F.P. used, does in fact decrease with time of travel in day-time experiments, the decrease being rapid at first. This appears to account for at least part of the 'loss' of F.P. found in the experiments. The decrease in brightness is much less during night-time experiments. The rate of decrease in brightness was found to be greater for a British than an American material, presumably because of the different activators used in their manufacture.

**The comparison of F.P. with an 'absolute' tracer.**—A fairly precise estimate for the apparent loss of material was obtained by comparing the F.P. with a radio-active tracer. The rate of decay of the radio-active material was known, and corrections for it were easily made.

Simultaneous releases of F.P. and radio-xenon ( $^{133}\text{Xe}$ , an inert radio-active tracer in gaseous form, with a half-life of 5.3 days) were made at the same position, at constant rates over periods of about two hours, and were sampled simultaneously at two positions about 15 and 60 km downwind. The  $^{133}\text{Xe}$  source was limited in size, so the two sampling stations were arranged as far as possible to lie continuously in the tracer's plume, by moving them from time to time. Since the half width of the plume was 5 or  $10^\circ$ , considerable care was needed in planning the experiments and siting the mobile observation points. Synoptic charts at hourly intervals are of little use in trajectory forecasting with this degree of accuracy. The technique used was to estimate the direction of travel of the tracers from the vector mean winds up to about 2000 feet, obtained from pilot-balloon ascents made quarter-hourly at the release point, and then to supplement these data with measurements of the position of the plume with a mobile F.P. sampler, each sample being examined immediately in a portable dark room. About six pairs of plume fixes were obtained in each of the three experiments in this way, each pair being transmitted to a control centre about 15 minutes after being made. The technique, used in conjunction with frequent communication with the sampling stations, was precise enough to secure success in the experiments. The xenon samples were corrected for decay and compared with the corresponding F.P. samples and showed that a mean apparent loss of about 50 per cent of the F.P. occurred during travel between the two sampling stations, or during the period from 1 to 3 hours after release.

An improved method of assessment of F.P. samples was introduced for the last of these experiments. This involved an increase of several times in the intensity of the ultra-violet illumination, together with vertical instead of oblique illumination of the sampler drums under the microscope. The same samples were also assessed by the original method and the numbers of particles found by both means were compared. The new assessment increased particle counts by between 20 and 30 per cent for samples from both the stations, but the overall percentage loss occurring during travel between stations was almost unchanged.

**General experimental precautions.**—The results of experiments using F.P. as a tracer are all too easily vitiated by contamination of sampling surfaces with F.P. This contamination can easily arise if the supplies of F.P. and the dispensing equipment are stored in buildings close to the sampling apparatus and the assessment laboratory. All experiments should as far as possible be planned to ensure that large enough samples are collected so that purely statistical variations are small. This implies suitably large sources of F.P., but on the other hand any experiment involving the use of this tracer should always be carried out with the smallest practicable source in order to reduce the inevitable contamination of such things as trees and buildings. The conflict of requirements often results in the source strength finally adopted being a compromise. If restrictions in the source are necessary, then the experiment requires more careful planning to be successful.

**Conclusion.**—Zinc cadmium sulphide is a useful tracer for meteorological studies of diffusion over a wide range of distances because of its comparatively easy detection and the great sensitivity of the technique. However, decay of the tracer does occur, chiefly when it is used during the day-time. In experiments designed to measure diffusive spread, such as the cross-wind or vertical spread of plumes or the along-wind growth of instantaneous cross-wind line sources, tracer decay is unimportant because in these cases one is only concerned with relative concentrations of the particles through a cross-section of the plume or line. However, difficulty is introduced in the assessment of absolute concentrations, although for night-time travel of 2 or 3 hours the tracer deficiencies can probably be ignored. Correction factors as large as 2 have to be applied to day-time results for similar times of travel in order to estimate absolute concentrations.

**Acknowledgements.**—The author wishes to thank the many people who contributed to this work, in particular Mr. G. F. Collins of the Chemical Defence Experimental Establishment (CDEE), Porton Down, who was responsible for many details of the tracer technique used in these experiments and who made the measurements of fluorescent brightness of F.P. Others involved were Dr. A. E. J. Eggleton and his colleagues at the Atomic Energy Research Establishment at Harwell, the Balloon Development Establishment at Cardington, Messrs. R. A. Titt, J. I. P. Jones and H. E. Butler of CDEE, and Dr. F. Pasquill who gave much advice.

#### REFERENCES

1. BRAHAM, R. R., SEELY, B. K., and CROZIER, W. D.; A technique for tagging and tracing air parcels. *Trans. Amer. geogr. Un., Washington D.C.*, **33**, 1952, p. 825.
2. PERKINS, W. A., LEIGHTON, P. A., GRINELL, S. W. and WEBSTER, F. X.; A fluorescent atmospheric tracer technique for mesometeorological research. *Proc. 2nd nat. Air Poll. Symp.*, Los Angeles, 1952, p. 42.

3. JONES, J. I. P. and BUTLER, H. E.; The measurement of gustiness in the first few thousand feet of the atmosphere. *Quart. J. R. met. Soc., London*, **84**, 1958, p. 17.  
4. CHAMBERLAIN, A. C.; Private communication, 1960.

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## OBSERVATIONS OF NOCTILUCENT CLOUD NEAR MIDWINTER

By R. A. HAMILTON

Until recently noctilucent cloud has been regarded as a phenomenon seen only in the summer (Ludlam<sup>1</sup>) but during the International Geophysical Year noctilucent cloud was observed from late March to early November by observers in the U.S.S.R. (Pavlova<sup>2</sup>). It seems almost certain that some form of noctilucent cloud was seen by four observers at Lerwick Observatory (60.1°N, 1.2°W) on 5 January 1964, from 1630–1655 Universal Time (UT) (sunset was at 1515 and civil twilight at 1611 UT).

The noctilucent cloud was first observed to the north-west at about 1630 UT as a band of white cirrus-like cloud at an elevation of about 60°, clearly contrasting with the weak red tinge of small patches of cirrus still visible. By 1640 the red-tinted cirrus had disappeared and the band of noctilucent cloud was clearly visible moving eastwards and by 1650 was almost vertically overhead; it was white against the sky which was now dark, though not sufficiently dark for the Milky Way to be seen. It was seen by three meteorological observers who without hesitation described it as having the appearance of cirrus cloud: it was in the form of filaments, very similar to that illustrated in Plate 42 of the abridged *International Cloud Atlas*.<sup>3</sup> The band was about 4° in width and about 10° in length and appeared to be moving or developing along the axis of the band at a rate of about 1½° per minute. It disappeared very soon after 1655 when an attempt was being made to telephone observers in other parts of Scotland. The sudden disappearance is consistent with the view that the cloud was sunlit.

It is very unlikely that it was part of an auroral arc that was seen—it was oriented at about 45° to the geomagnetic meridian, and differed in appearance from any aurora any of the observers had ever seen. The Lerwick magnetograms showed that magnetic conditions were very quiet at the time—the *K*-index was 1.

At 1655 UT the depression of the sun was 10° 45'. If it is assumed that the cloud was overhead and just illuminated at 1655 and that the refraction was twice 34' (see *Meteorological Glossary*<sup>4</sup>), then the calculated height was 91 km—somewhat higher than the mean height of 82 km in summer—and the cloud velocity was roughly 40 metres/second towards the south-east. This is in reasonable agreement with the observation of Greenhow and Neufeld<sup>5</sup> who give the mean January wind at a height of 85 to 100 km as 17 m/s towards east and south-east. However the height must have been considerably in excess of this height as the light from the sun which passes through the lower layers of the atmosphere would be too weak to illuminate the cloud.

As it has been thought that cosmic dust plays an important part in the formation of noctilucent clouds, it may be significant that this noctilucent cloud was observed at the time of the Quadrantid meteor shower 3–4 January: it was on a rather smaller scale than the usual summer observations, and somewhat higher, and may have been produced by dust from this meteor shower.

It is interesting to note too that its appearance was preceded by a steady rise of pressure of 20 mb during the preceding days, and that the lower half of the atmosphere was abnormally warm in the area to the north of Scotland during December 1963 and January 1964: Grišin<sup>6</sup> reported that the occurrence of noctilucent cloud in the U.S.S.R. was always preceded by a more or less long and rapid increase of surface pressure, and was always associated with abnormally high temperatures over a wide area, especially during the preceding month. Paton<sup>7</sup>, however, found that these conditions do not occur in the case of noctilucent cloud in north-west Europe.

#### REFERENCES

1. LUDLAM, F. H.; Noctilucent clouds. *Tellus, Stockholm*, **9**, 1957, p. 341.
2. PAVLOVA, T. D.; Noctilucent cloud investigations. Leningrad, University Press, 1960, p.3 (in Russian).
3. Geneva, World Meteorological Organization (WMO). International Cloud Atlas. Abridged Atlas. Geneva, WMO, 1956.
4. Meteorological Office. Meteorological Glossary. Fourth edn. London, HMSO, 1963, p. 246.
5. GREENHOW, J. S. and NEUFELD, E. L.; Winds in the upper atmosphere. *Quart. J. R. met. Soc., London*, **87**, 1961, p. 472.
6. GRIŠIN, N. I.; Wave motion and meteorological conditions for the appearance of noctilucent clouds. *Ann. int. geophys. Yr., London*, **11**, p. 20. (Translation also available in National Aeronautics and Space Administration, Washington D.C., Tech. Trans. F-84, 1963, p. 7.)
7. PATON, J.; Noctilucent cloud. *Met. Mag., London*, **93**, 1964, p. 161.

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## DELAYED CLEARANCE OF LOW CLOUD BEHIND COLD FRONTS AT MANCHESTER AIRPORT

By L. DENT

**Summary.**—Delayed clearances of cloud behind cold fronts at Manchester have been examined for 32 cases occurring during 1959–62. The phenomenon is thought to be caused by the lifting of moist frontal air and is most marked with geostrophic wind directions between  $310^\circ$  and  $330^\circ$ . In most cases cloud lifts to above 1000 feet within 3 hours. Diagrams are given which can be used for forecasting (from the wind in the cold air and the mean dew-point depression in the frontal zone) (a) the length of delay in clearance and (b) the lowest cloud base behind the cold front. Seasonal and diurnal effects are noted and also the effect of curvature of the isobars. Two examples are quoted with synoptic charts.

**Introduction.**—The passing of a cold front is usually marked by lifting of the cloud base and a dispersal of low stratus, often followed by broken cloud. Occasionally however, this improvement is delayed for several hours after the passage of the front. At Manchester Airport cold fronts approaching from the north-west are frequently marked by a sudden lowering of the cloud base often to 200 ft above airfield level, causing temporary disruption to aircraft operations. The clearance of this low cloud varies from one front to another and on occasions has been delayed for over 6 hours. On the other hand, cold fronts followed by south-westerly winds are usually free from low stratus in the cold air. These differences may in part be explained by topography in terms of shelter and exposure as shown in Figure 1. Air reaching Manchester from a direction between  $270^\circ$  and  $330^\circ$  must cross the Irish Sea and, after reaching Manchester, is subsequently lifted over or is deflected by the Pennines. From other wind directions the air reaching the Airport is modified by high ground or by a long land track.

**Previous work.**—Previous work on the study of cold fronts has dealt mainly with the structure of the frontal boundary. In 1951 Sansom<sup>1</sup> introduced the classification of anafront or katafront by using two simultaneous soundings of wind and temperature. More recently Miles<sup>2</sup> has discussed the presence of

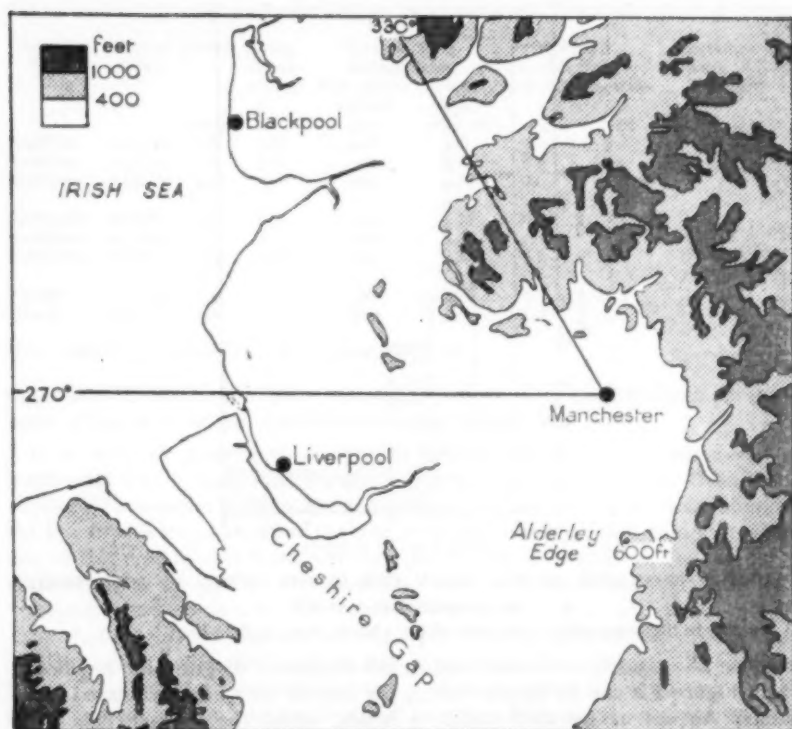


FIGURE 1—MAP OF THE MANCHESTER AREA

The bounding lines  $270^{\circ}$ - $330^{\circ}$  have been drawn from Manchester City. Similar lines drawn from the Airport (near to Alderley Edge) include very little high ground.

sharp humidity boundaries ahead of some cold fronts at levels about 700 mb. Morris<sup>3</sup> has studied delayed clearances behind cold fronts at selected stations in the United Kingdom. He suggests that delays in the cessation of rainfall are associated with relaxing upper troughs on a synoptic scale, whilst delays in the clearance of low cloud are thought to occur on a meso-scale and follow different patterns at different stations.

Following the investigation by Morris, 30 cold fronts and 2 non-frontal troughs have been examined at Manchester Airport for the 3 years September 1959 to September 1962. These fronts and troughs all reached Manchester from the north-west and were included in the analyses of the *Daily Weather Report*.<sup>\*</sup> The sample does not include any quasi-stationary fronts nor those with noticeable wave development.

As a measure of the delay in cloud clearance, the time taken from the passage of the surface front to the lifting of the low stratus to over 1000 ft above airfield level was chosen as the most suitable parameter, and is referred to as *D* in the notes which follow. Figure 2 shows the frequency of such delays amongst the 32 cases studied. The delays are grouped in time steps of one hour. When *D* was a whole hour it has been grouped with the time range below that value, for

<sup>\*</sup>Meteorological Office. *Daily Weather Report*. London, HMSO.

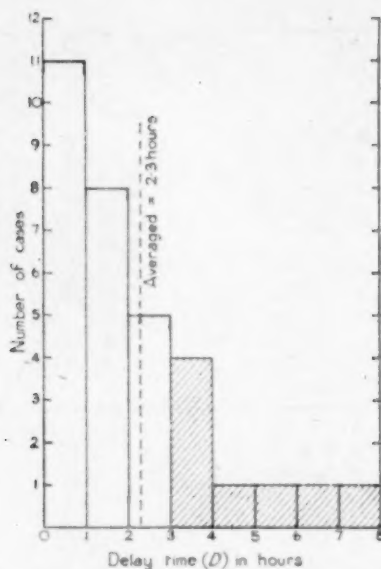


FIGURE 2—FREQUENCY OF THE DELAY TIME IN THE LIFTING OF LOW STRATUS, IN RANGES OF 1 HOUR

$D$  = delay in the lifting of low stratus to above 1000 ft above airfield level.

instance  $D = 3.0$  hours is included in the frequency diagram for 2-3 hours. From Figure 2 it can be shown that 75 per cent of the 32 fronts cleared Manchester Airport as specified within 3 hours, whilst the average delay was 2.3 hours. The remaining 8 cases (25 per cent) had delayed clearances ranging from 3.5 to 7.5 hours and these are considered in detail.

**Classification of fronts.**—By examining the winds and temperature soundings at a conveniently placed ascent through the cold air, the 32 cases were classified as shown in Table I.

TABLE I—CLASSIFICATION OF CASES OF DELAYED CLEARANCE

Analysis type	Number	Mean delay hours	Number with delay over 3 hours
Katafront	22	1.9	3
Anafront	6	3.3	3
Troughs	2	5.7	2
Doubtful	2	1.0	0

The eight cases with  $D$  greater than 3 hours are listed in Table II.

Table I shows that anafronts, although uncommon as a class (6 cases out of 32), produced delayed clearances of over 3 hours quite often (3 cases out of 6). The non-frontal troughs cleared slowly and so did a few katafronts (3 cases out of 22).

The lowest cloud bases ranged from 100 to 900 ft above airfield level and 11 out of 32 cases had cloud at 200 ft or below. The lowest cloud usually occurred at the passage of the surface front and thereafter a steady but often slow improvement followed. These cloud features were common to the three analysis types, and it seems therefore that this classification is probably less

TABLE II—DETAILS OF CASES OF DELAY IN CLEARANCE GREATER THAN 3 HOURS

Analysis type	Date of delay	Delay	Mean cloud amount	Lowest cloud during delay		Rainfall with front		Curvature of isobars in the cold air*
				Base above airfield	Mean cloud amount	Amount	Duration	
		hours		feet		mm	hours	
Anafront	19.1.60	3.5	5/8	400	2/8	3.0	3.0	C
Anafront	13.1.61	7.0	6/8	100	5/8	8.5	8.9	A
Anafront	24.8.61	4.5	5/8	200	3/8	8.6	3.0	A
Katafront	22.6.61	4.0	6/8	100	2/8	0.5	1.4	A
Katafront	29.3.62	3.5	8/8	200	5/8	0.1	0.2	C
Katafront	16.6.62	5.5	5/8	200	2/8	2.2	1.5	A
Trough	1.1.60	7.5	7/8	400	4/8	1.5	1.2	C
Trough	22.7.62	4.0	5/8	200	2/8	3.0	2.4	C

\*C = cyclonic curvature, A = anticyclonic curvature

important in detecting a likely delayed clearance than the combined arrangement of low-level winds, temperatures and topography.

It is probably possible to distinguish further between cold fronts from the north-west which have north-westerly winds in the warm sector from those with south-westerlies in the warm sector. In the former case, which is uncommon, the low stratus forms ahead of the cold front and clears quickly behind it. Only one of this type of cold front was included in the 30 examined, but one more conforming to the pattern described has occurred since September 1962. The remainder had south-westerly winds in the warm sector and it is amongst these that a delayed clearance is likely. With this type of front the surface wind at Manchester is often held well back to south by the flow through the Cheshire Gap. This sharpens the frontal trough and accentuates the wind veer on the front. In addition the lowering in cloud base is sudden as the wind swings from a sheltered to an exposed direction.

**The factors controlling a delayed clearance.**—After the passage of the front the presence of low stratus is probably controlled by the wind direction and speed in the cold air, and by temperature and dew-point separation. Frontal development may also be significant, but its effect would be more noticeable at levels above the low-stratus layers.

The delay in clearance of low cloud, and probably the level to which the cloud lowers, will vary in the first instance with the post-frontal wind direction which is influenced by topography. It seems reasonable also, to suppose that higher wind speeds and larger dew-point depressions will each contribute to a quicker clearance of low cloud and to higher cloud bases.

Denoting the geostrophic wind in the cold air as from direction  $F$  (degrees) at speed  $S$  (knots) and the mean dew-point depression in the frontal zone as  $\theta$  (degrees Celsius), both the delay  $D$  and the cloud base may be expected to vary with  $F$  and the product  $S \times \theta$ . A representative value of  $\theta$  is obtained by taking the mean of six stations, three on each side of the cold front.

On Figure 3 the product  $S\theta$  is plotted against  $F$  and beside each point is noted the delay  $D$ . Isopleths of  $D$  are drawn and these confirm that for a given wind direction the delay  $D$  decreases for increasing values of the product  $S\theta$ . The most significant feature is the region of maximum values of  $D$  associated with the geostrophic winds between  $310^\circ$  and  $330^\circ$ . These directions correspond

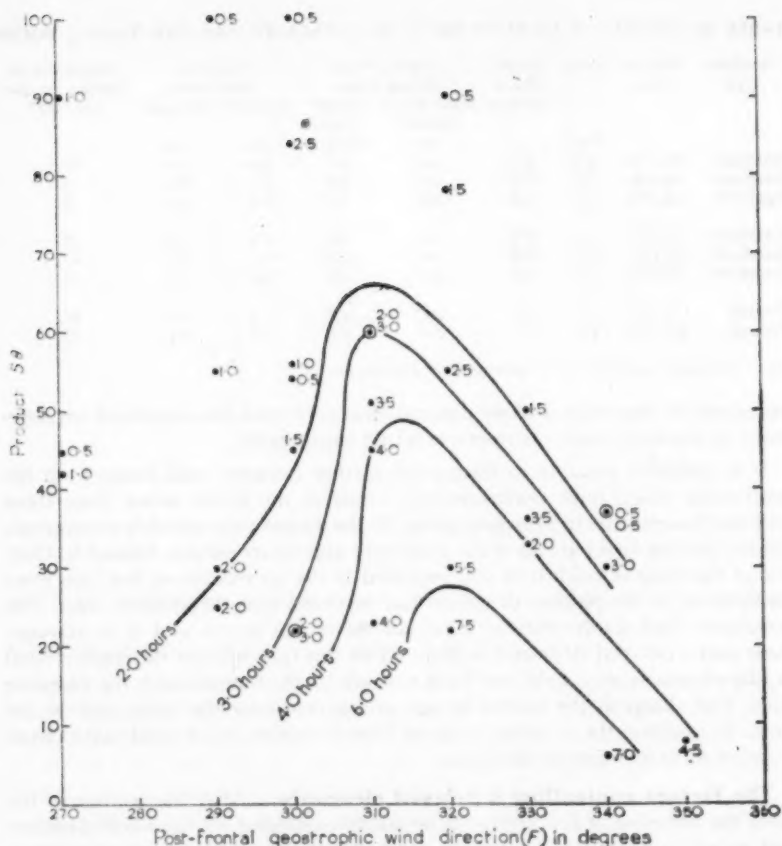


FIGURE 3—ISOPLETHS OF DELAY TIME RELATED TO WIND DIRECTION AND PRODUCT  $S\theta$

$S$  = geostrophic wind speed in the cold air, in knots.

$\theta$  = mean dew-point depression of the frontal zone, in  $^{\circ}\text{C}$ .

to the longest sea track over the Irish Sea to which air can be exposed before reaching Manchester Airport, and also along these directions air is lifted over Alderley Edge, 4 miles away (see Figure 1). Only short delays occur when  $F$  lies between  $270^{\circ}$  and  $300^{\circ}$ , and because of sheltering effects a sharp transition takes place around  $340^{\circ}$ .

On Figure 4 the product  $S\theta$  is again plotted against  $F$  and beside each point is noted the lowest cloud base. Smooth lines have been drawn to embrace the points with cloud base at 200 ft and also, though with some uncertainty, at 600 ft. The shape of the 600-ft line is difficult to explain, but it is of secondary importance compared with the 200-ft line which is well supported by the observations, and shows a peak between  $310$  and  $330^{\circ}$  similar to that in Figure 3. Altogether 27 out of 32 cases fit the lines of Figure 4 as drawn, and 29 out of 32 fit the lines of Figure 3.

**Seasonal and diurnal effects.**—Table III gives the seasonal distribution of the fronts.

TABLE III—SEASONAL DISTRIBUTION OF THE FRONTS

Season	All cases Number	Mean delay hours	Cases with cloud base 200 ft or below	Cases with delay over 3 hours
Mar.-May	7	1.4	2	1
June-Aug.	11	2.6	5	4
Sept.-Nov.	7	1.8	2	0
Dec.-Feb.	7	3.7	2	3
Total	32		11	8

Whilst the incidence of cold fronts from the north-west was spread fairly evenly through the seasons, delayed clearances of over 3 hours were more common during winter and summer than in the transitional months.

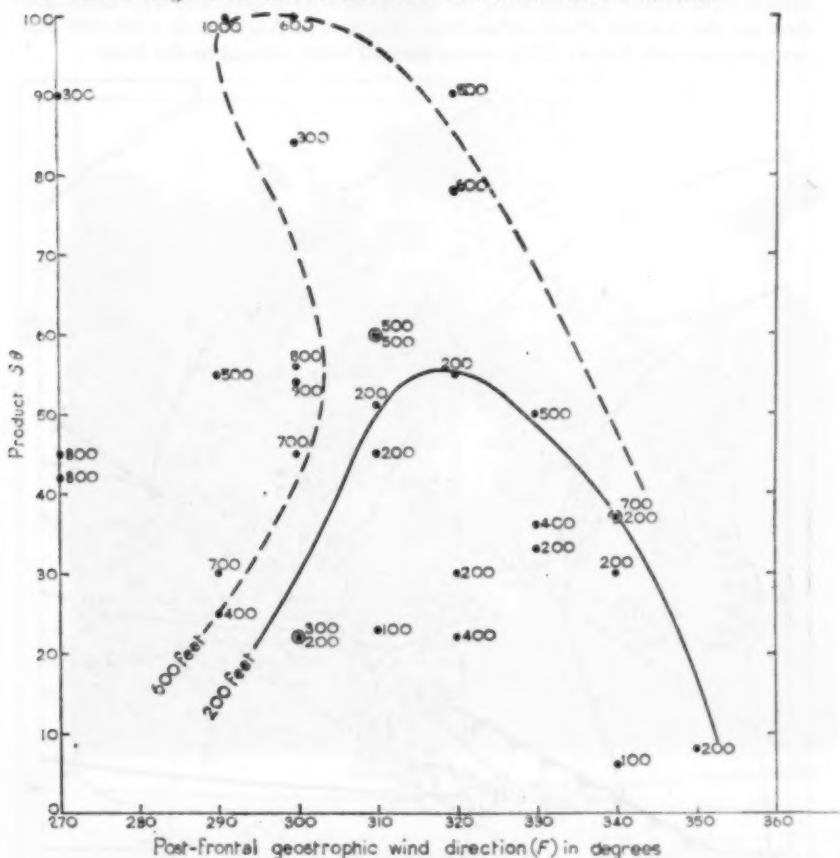


FIGURE 4—ISOPLETHS OF LOWEST CLOUD BEHIND THE COLD FRONT RELATED TO WIND DIRECTION AND THE PRODUCT  $S\theta$

$S$  = geostrophic wind speed in the cold air, in knots.

$\theta$  = mean dew-point depression of the frontal zone, in  $^{\circ}\text{C}$ .

Errata—the cloud base at  $F290^{\circ}$ ,  $S\theta = 100$  should be 600ft.

An examination of times of frontal passage reveals that 7 out of 8 cases with  $D$  over 3 hours occurred between 2200 and 0900 GMT, the one day-time cold front passing Manchester at 1530 GMT in January.

**Curvature effects.**—Anticyclonic curvature of the isobars in the cold air was most common amongst the whole sample of fronts (19 cases out of 30) and also amongst the fronts with delayed clearances of over 3 hours as shown in Table II. The two trough lines excepted, the four longest delays in clearance were all accompanied by anticyclonic curvature.

**Examples.**—Details are given of 2 occasions of delayed clearance at Manchester.

(i) *Anafront*: 13 January 1961.—This front passed through Manchester Airport at 0850 GMT and moved south-east at 12 kt. The anafront classification is confirmed from Figure 5(a) showing the post-frontal rain belt, and by Figure 5(b) showing the absence of any subsidence inversion at Aughton at 1100 GMT and the decrease with height of the component of wind normal to the front.

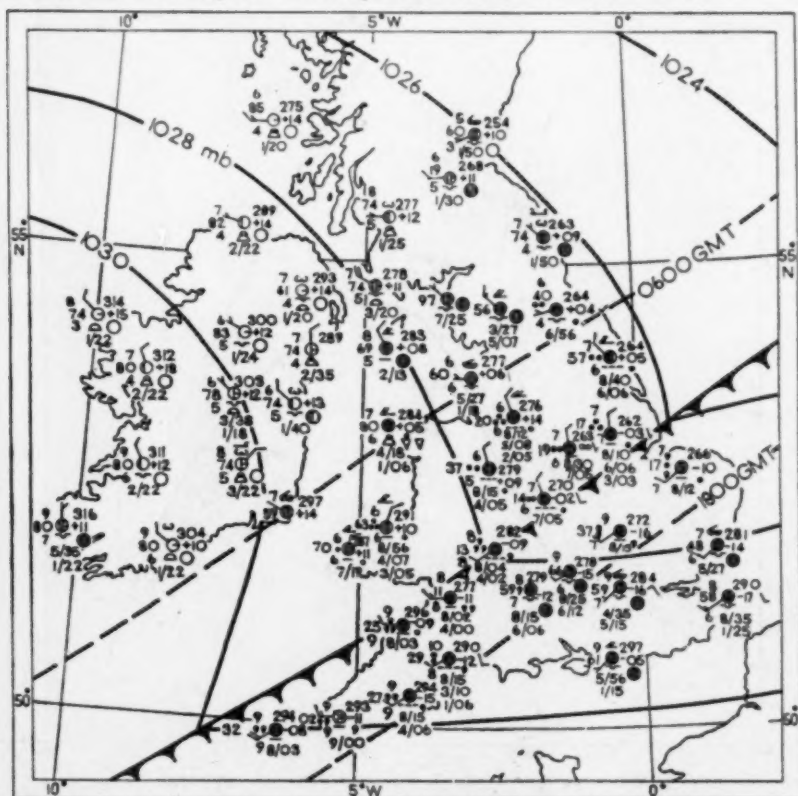


FIGURE 5(a)—ANALYSIS FOR 1400 GMT, 13 JANUARY 1961

The position of the cold front at 0600 and 1800 GMT is shown by a pecked line

Ahead of the front, 2.1 mm of rain was recorded at Manchester Airport whilst 6.4 mm fell between 0900 and 1430 GMT. Figure 5(c) shows the variation



*Crown copyright*

PLATE I—APPARATUS USED IN VERTICAL DIFFUSION EXPERIMENTS

One of the sampling units has been attached to the cable of the captive balloon and is being tested before being hauled aloft. Above it is an instrument for measuring the inclination of the wind to the horizontal and the wind speed (see page 193).

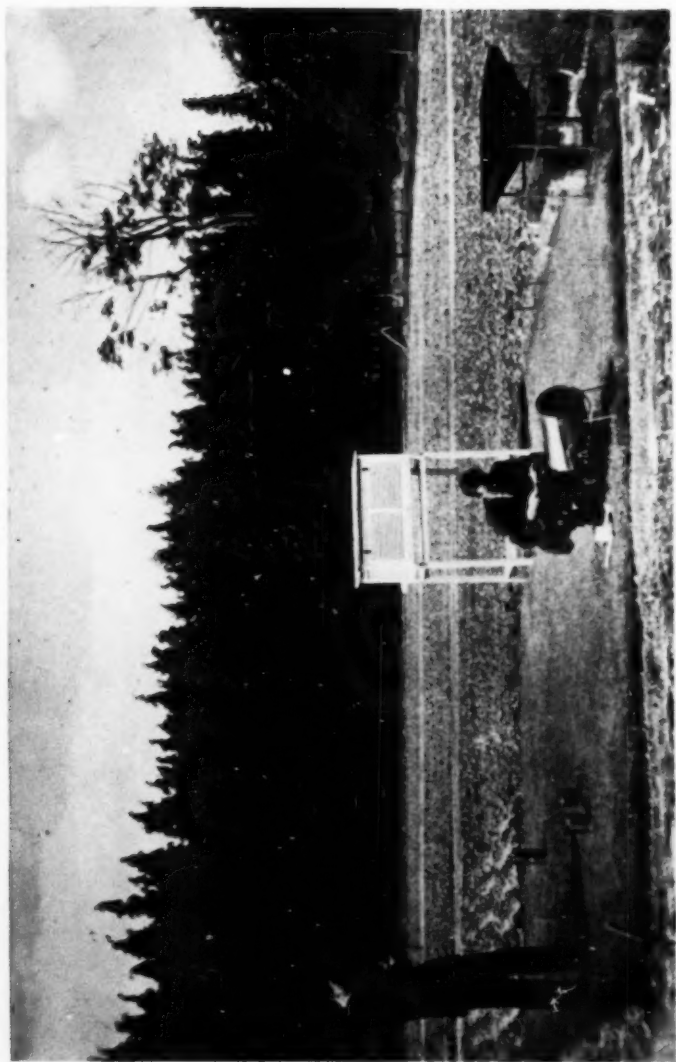
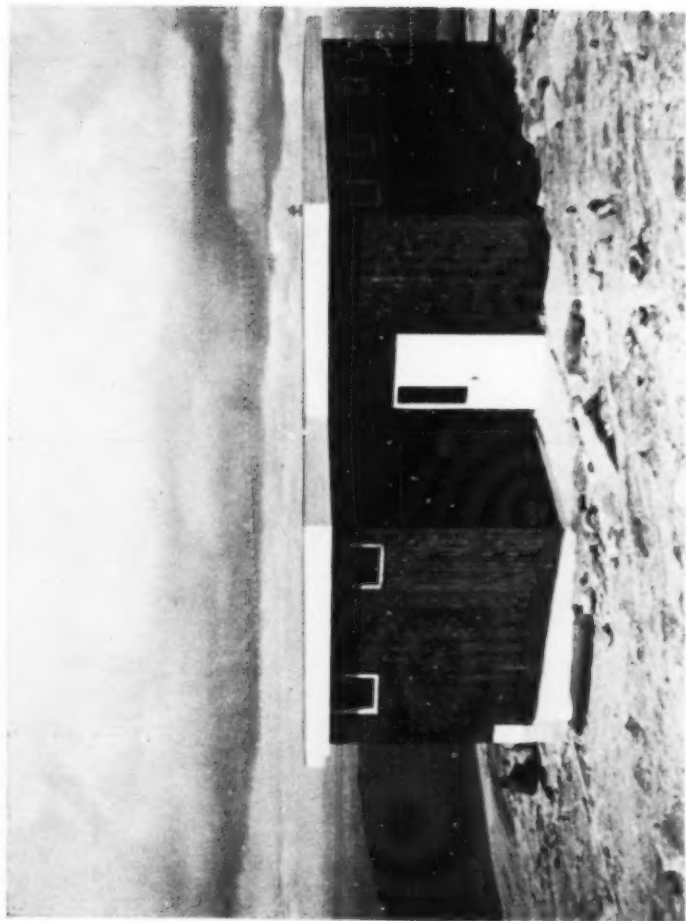


PLATE II—POSITIONS OF RAIN-GAUGES AND TROUGH (RIGHT) LOOKING NORTH,  
BAGLEY WOOD, OXFORD  
See also Figure 1 on page 214.

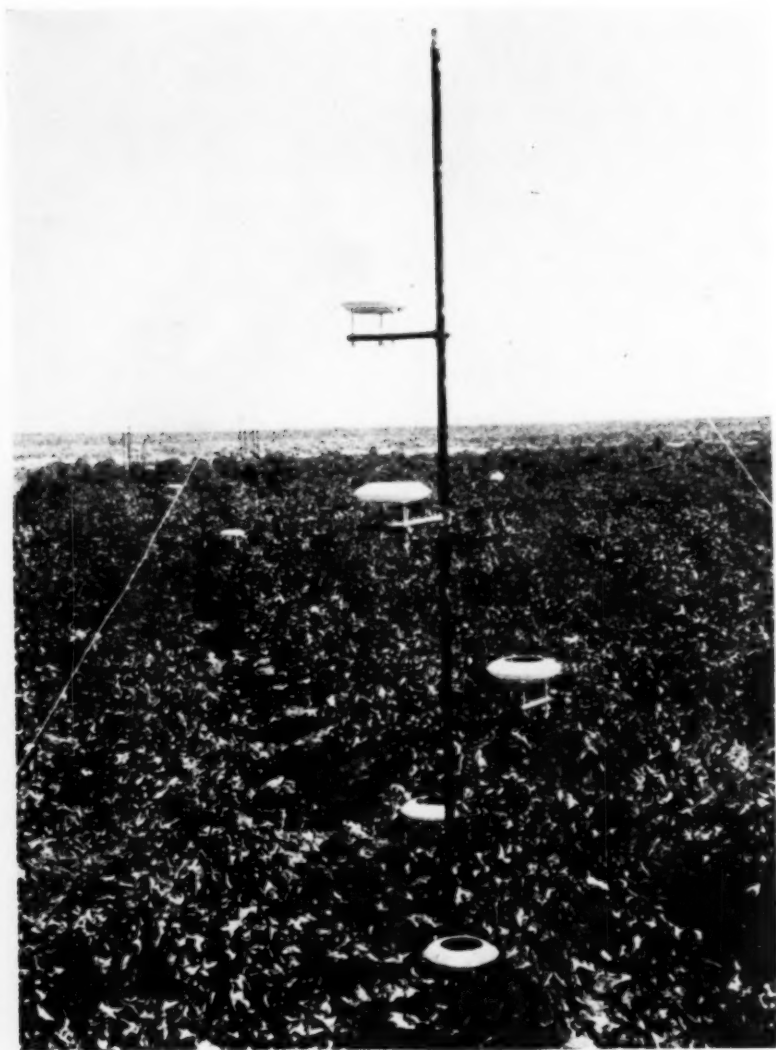


*Green copyright*

PLATE III—SUNSHINE RECORDER SITED ON THE ROOF AT THE TOP STATION OF  
THE CAIRNGORM CHAIRLIFT IN COIRE CAS

Instruments, including rain-gauge and thermometers, were installed at this high-level station in the Cairngorms in June 1963. The sunshine recorder is 3615 feet above mean sea level.

To face p. 209



*Photograph by J. P. Hudson*

PLATE IV—APPARATUS WITH MOUNTED EVAPORIMETERS USED IN THE GEZIRA  
EXPERIMENTS  
See page 218.

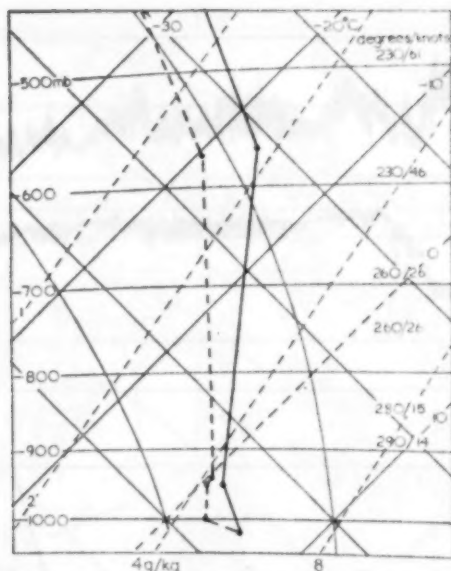


FIGURE 5(b)—TEPHIGRAM FOR AUGHTON, 1100 GMT, 13 JANUARY 1961  
 — Dry-bulb temperatures; - - - dew-point temperatures.  
 Winds are shown at standard levels.

of cloud base from 0600 to 1800 GMT and also a copy of the pressure-tube anemogram. In common with most cold fronts from the north-west at Manchester, the cloud base fell suddenly, in this case from 600 ft to 100 ft, as the wind veered. After about one hour the cloud began to lift slowly and by 1600 GMT was above 1000 ft. At 1800 GMT low stratus returned with base varying between 500 ft and 1000 ft before lowering into fog and reducing visibility to 30 yards by 0000 GMT on 14 January 1961. The fog persisted until the morning of 15 January but its formation, preceded by a return of low stratus, was due to cooling assisted by the clearance of the frontal cloud which was judged to occur soon after 1600 GMT on 13 January.

After the frontal passage at 0850 GMT the geostrophic wind veered to  $340^\circ$  12 kt and the dew-point depression of the air in the frontal zone was  $0.5^\circ\text{C}$ , so that the front was noted on Figure 3 by  $F = 340^\circ$  and  $S\theta = 6$  with 7.0 hours delay.

Table IV compares the duration of post-frontal cloud below 1000 ft and also the duration of rainfall (post-frontal) for four stations, Blackpool, Manchester, Shawbury and Birmingham. This information was deduced from hourly charts.

TABLE IV—POST-FRONTAL CLOUD AND RAINFALL FOR ANAFRONT EXAMPLE

Station	Delay	Lowest cloud base	Duration of
	hours	above airfield	rainfall
		feet	hours
Blackpool	4	500	6
Manchester	7	100	6
Shawbury	4	300	4
Birmingham	3	400	3

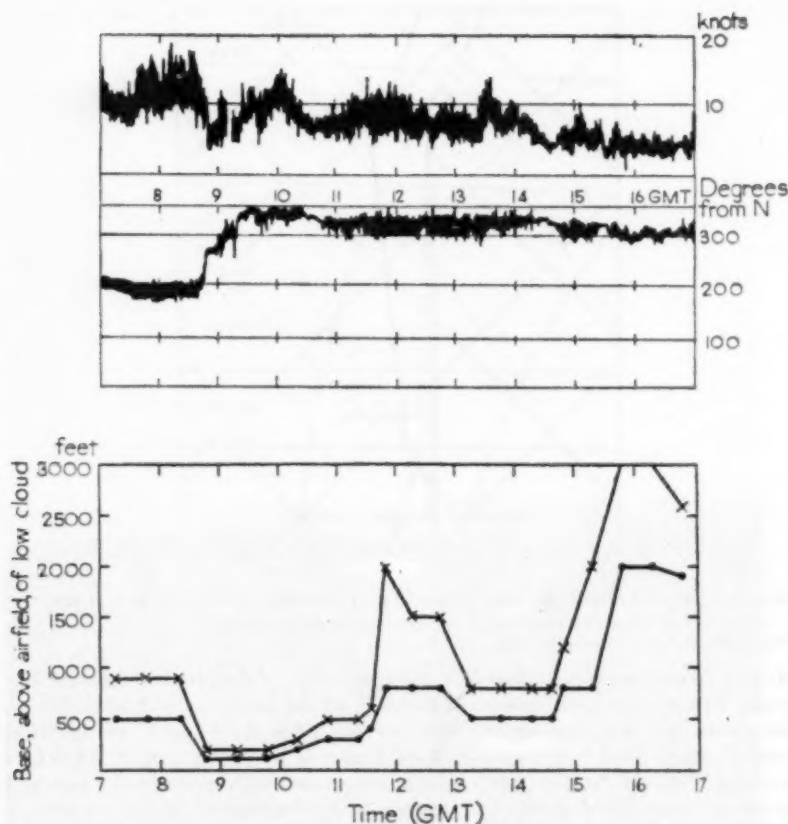


FIGURE 5(c)—ANEMOGRAM FOR MANCHESTER AIRPORT AND CHANGES IN THE BASES OF LOW CLOUD ON 13 JANUARY 1961

The top diagram shows the anemogram (pressure-tube anemograph) and the bottom diagram the changes in the low cloud.

— Base above airfield of the lowest layer of stratus; x-x-x-x base above airfield of second layer.

*Errata*—the first three points of the lowest cloud layer should be at 600 ft.

From Table IV it might be considered that the duration of low stratus is linked to the duration of rainfall. This may be so with anafronts but a second example is described which will show that low stratus is also a feature of katafronts with little rain.

(ii) *Katafront*: 22 June 1961.—On this occasion the cold front passed Manchester Airport around 0800 GMT with the surface wind veering gently from 220 to 290° between 0700 and 0800 GMT. The temperature rose 2°C by 0900 GMT because diurnal heating more than compensated for any air-mass changes. Only 0.5 mm of rain fell between 0600 and 0800 GMT and a trace between 0800 and 1200 whilst successive hourly charts showed the front to be weak with respect to rain and frontal contrasts. Figures 6(a) and 6(c) confirm that it was a weak katafront. Nevertheless the cloud base at Manchester Airport fell from 800 ft at 0600 GMT to 100 ft by 0730 and Figure 6(b) indicates how this



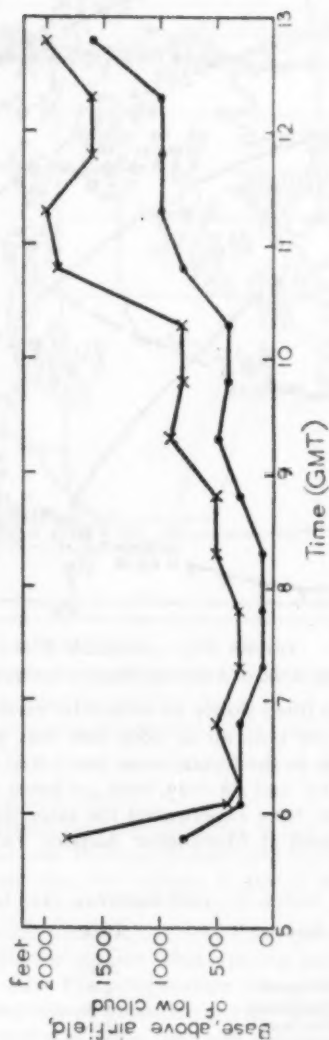
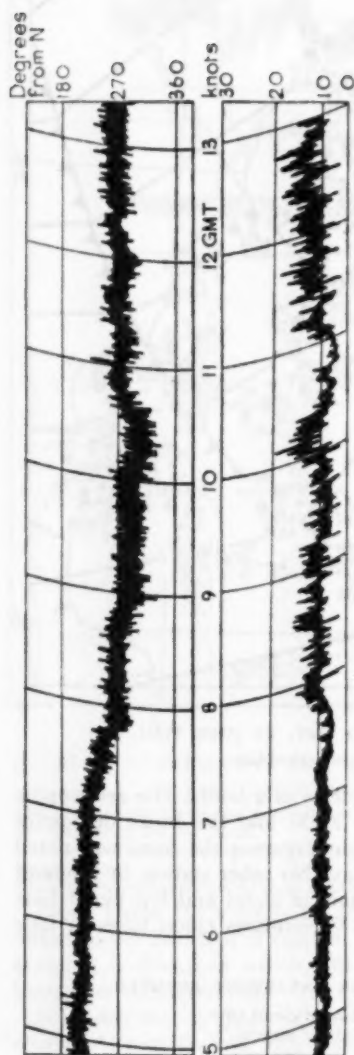


FIGURE 6(b)—ANEMOGRAM FOR MANCHESTER AIRPORT AND CHANGES IN THE BASES OF THE LOW CLOUD ON 22 JUNE 1961  
 The top diagram shows the anemogram (electrical anemograph) and the bottom diagram the changes in the low cloud.  
 — Base above airfield of the lowest layer of stratus; x-x-x base above airfield of second layer.

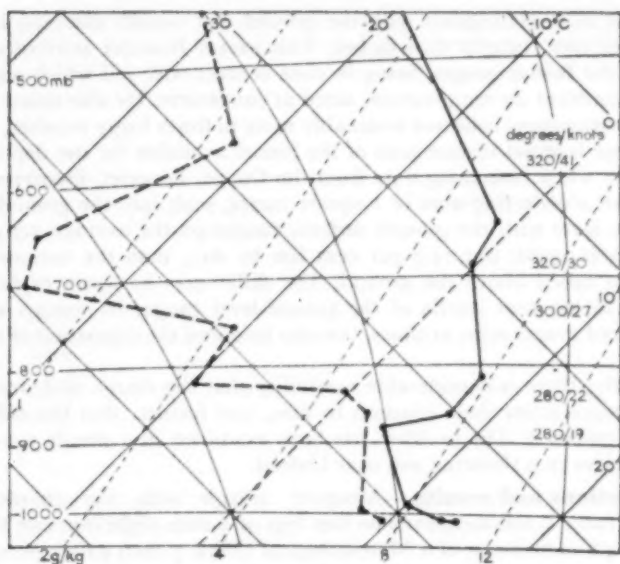


FIGURE 6(c)—TEPHIGRAM FOR AUGHTON, 1100 GMT, 22 JUNE 1961

———— Dry-bulb temperatures; - - - - dew-point temperatures.  
Winds are shown at standard levels.

#### REFERENCES

1. BANSOM, H. W.; A study of cold fronts over the British Isles. *Quart. J. R. met. Soc., London*, **77**, 1951, p. 96.
2. MILES, M. K.; Wind, temperature and humidity distribution at some cold fronts over SE. England. *Quart. J. R. met. Soc., London*, **88**, 1962, p. 286.
3. MORRIS, R. M.; Unexpected delays in clearances behind cold fronts. *Met. Mag., London*, **91**, 1962, p. 304.

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#### DEW IN RAIN-GAUGES

By E. R. C. REYNOLDS, Ph.D.

Department of Forestry, University of Oxford

**Introduction.**—The condensation in rain-gauges of water from a moist atmosphere depends upon the heat relations of the collecting funnel. The surface temperature of the funnel may fall below air temperature by heat losses through conduction and radiation: condensation occurs when the temperature of the surface reaches the dew-point. The amount of dew collected depends on the transport of water vapour to the surface and the dissipation of latent heat. Since the latter differs from one design or rain-gauge to another, it may account for some of the differences in behaviour between gauges.

#### Reports of differences in gauge performance attributed to dew.

Poncelet<sup>1</sup> compared various standard national gauges at Brussels, and discovered that the British Meteorological Office 8-inch gauge registered a relatively greater catch in the months of January to March. This was particularly the case when gauge catches within two or three days after periods of frost were compared. For 10 such periods (28 rain days) the total amounts caught by duplicate 8-inch gauges were 2.42 and 2.44 inches, whereas a

gauge not in direct contact with the ground and usually catching a similar amount of rain, caught 2.20 inches. This excess Poncelet attributed to the fact that the British gauges, being in close contact with soil which was colder than the ambient air temperature, acted as condensers. He also noted that the German rain-gauges collected noticeably more in frosty foggy weather, because of the large internal surface area of the funnel available for the deposition of frost. Even when examining data from the Congo, Poncelet discovered that a gauge with a collecting area of 1 square metre, sunk into the ground so that its lip was level with the ground surface, caught on the average 7.3 per cent more rain at night, but 14.9 per cent less by day, than the national gauge which was raised above the ground. The differences he again explained by reference to the heat inertia of the ground-level gauge; its contact with the soil favoured evaporation at times, but also favoured the deposition of morning dew.

Evidently, there is considerable possibility that the design and installation of rain-gauges affect their relations to dew, and further, that the differences may be significant. The problem has been examined in a simple comparison of rain-gauges in a sheltered site near Oxford.

**Installations and results.**—A copper trough with the characteristics shown in Table I, was supported on four legs of  $\frac{3}{4}$ -inch angle iron (see Plate II) and sited 4.6 metres east of a Meteorological Office 5-inch gauge set up in the standard manner (see Plate II and Figure 1). A second 5-inch gauge was installed 2.7 metres north of the first. The base of the Meteorological Office rain-gauge is buried 19 cm below ground level.

Gauge	TABLE I—CHARACTERISTICS OF THE RAIN-GAUGES				
	Height of lip	Weight of copper and brass	Shape	Details of funnel Collecting area	Internal surface area
	cm	kg		square metres	
Trough	77.5	7.7	rectangular	0.566	1.022
5-inch gauges	30.5	1.8	circular	0.0127	0.061

As examples of the difference between the gauges in their efficiency to catch dew, Table II shows three records unaffected by rainfall. In these cases the greater collection of dew by the trough gauge is very evident, and the effect over a year might be appreciable. The difference amounts to between 0.002 and 0.003 inches of water on average condensed each night.

TABLE II—CONDENSATION IN GAUGES IN THE ABSENCE OF RAINFALL				
Date	Days since previous reading	Met.O. 5-inch gauges 'north' 'south'		Trough gauge
		inches		inches
11.10.62	8	0.006	0.006	0.027
18.10.62	7	0.003	0.003	0.016
8.12.62	12	0.005	0.009	0.047

Table III shows the relationship between the precipitation measurements from the gauges for each 3-monthly period over 2 years. From these it is evident that the trough is consistently less efficient at catching rainfall, perhaps because of its greater height, more evaporation, or less in-splash. However, the trough consistently collected more dew, if this is the correct explanation of the constant term. Possibly as a result of these opposing effects, the annual total for 1961 showed an excess collection of 0.24 inches by the trough, whereas 1962 showed a slight excess by the 5-inch gauges, perhaps reflecting a difference in the distribution of the sizes of storms between the two years. The difference

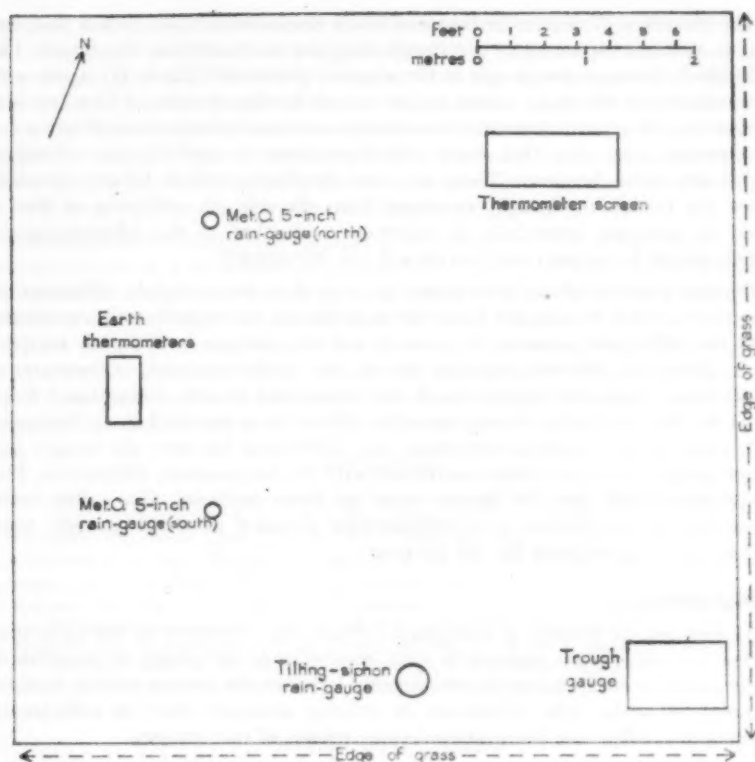


FIGURE 1—PLAN OF THE SITE USED IN THE COMPARISON BETWEEN RAIN-GAUGES AND TROUGH, BAGLEY WOOD, OXFORD

Trees to the south-south-west of the site give an angle of elevation of  $27^\circ$ , otherwise there is no obstruction within the conventional distance-height 2:1 rule. See also Plate 1.

TABLE III—SIMPLE LINEAR REGRESSIONS OF TROUGH CATCH( $\bar{Y}$ ) ON MEAN 5-INCH GAUGE CATCH( $\bar{x}$ ) (INCHES OF PRECIPITATION)

Period	1961	1962	Ratio of regression constant to mean number of nights per record	
			1961	1962
'Winter' (Jan.-Mar.)	$\bar{Y} = 0.0043 + 0.989\bar{x}$	$\bar{Y} = 0.0032 + 0.981\bar{x}$	0.0013	0.0009
'Spring' (Apr.-June)	$\bar{Y} = 0.0037 + 0.999\bar{x}$	$\bar{Y} = 0.0052 + 0.981\bar{x}$	0.0013	0.0013
'Summer' (July-Sept.)	$\bar{Y} = 0.0049 + 0.975\bar{x}$	$\bar{Y} = 0.0031 + 0.978\bar{x}$	0.0017	0.0012
'Autumn' (Oct.-Dec.)	$\bar{Y} = 0.0061 + 0.976\bar{x}$	$\bar{Y} = 0.0106 + 0.951\bar{x}$	0.0029	0.0037

between the constants of the seasonal regressions in Table III is not significant, neither is the difference between slopes. However, it may be noted that the highest constant occurred in autumn in both years. If the constants are rightly attributable to dew formation, it would be logical to adjust them according to the mean number of nights to which the rainfall collections refer in each season, since this varies from 2.1 to 4.1 nights per record. The adjusted figures are shown in the last two columns of Table III, where it is seen that the difference

in the efficiency of dew collection is about a thousandth of an inch a day, but that in autumn the excess in the trough may rise to three times this figure. The differences between the gauges in the absence of rainfall (Table II) agree with this estimate of the daily excess in the trough for the months of October and December. Monteith<sup>2</sup> notes that maximum nocturnal relative humidities occur in autumn, and also that from mid-September to mid-October cloudless nights are most frequent. These are two conditions which favour dew-fall. Since the trough is virtually insulated from the soil, its collection of dew is likely to contrast (especially in autumn) with that of the Meteorological Office gauges in contact with warm soil (cf. Monteith<sup>3</sup>).

Further analysis of the data failed to show that mean nightly difference in the catch of dew (computed from the regressions) was significantly correlated with the difference between the 12-inch soil temperature and the air temperature. However, this was probably due in part to the exclusion of measures of cloud cover and wind speed which are important in dew formation.<sup>2</sup> Even when the dew deposition from a recorder (Hirst<sup>4</sup>) was included as an 'independent variable' in a multiple regression, the differences between the trough and 5-inch gauges were not closely correlated with the temperature differences. The temperature and dew-fall figures used in these analyses, since they were measured on instruments at a considerable distance from the gauges, were perhaps too approximate for the purpose.

#### Discussion.—

(i) *Dew and the accuracy of rain-gauges.*—Since the efficiency of the collection of dew by rain-gauges appears to vary according to the design or installation of the gauge, it complicates the relationship between the gauges used in various national networks. This difference in relative accuracy may be sufficiently important to affect the international comparisons of rain-gauges.

Certain types of rain-gauges which have been suggested as an approach to the absolute measurement of rainfall by eliminating splash and wind effects, have been partially buried in the soil. Such designs will be particularly influenced by the thermal lag of the soil, and thus their collection of dew will be distinct from other types of gauge. This must be considered to detract from their value as absolute gauges.

(ii) *Inclusion of dew-fall in precipitation measurements for hydrological purposes.*—In connexion with water-balance studies, the suggestion has been made<sup>5</sup> that the condensation and absorption of water on the vegetation and in the soil is of considerable importance and ought to be added to the rainfall (although the magnitude of dew-fall was over-estimated in early experiments<sup>6</sup>). An instrument which measures rainfall, but also records dew-fall, might be considered more suitable for hydrological purposes. However, the measurement of dew-fall on the artificial collecting surface of a rain-gauge is probably very different from the amount of dew-fall on soil and vegetation;<sup>3</sup> and is considerably affected by the design and installation of the gauge.

A weighed lysimeter in Ohio has been employed for recording dew and rainfall,<sup>8</sup> since it provides a more or less natural vegetated surface. However, it is probable that dew-fall and transpiration were sometimes simultaneous, when neither was detected by this instrument. It appears<sup>2</sup> that an important proportion of the dew is merely the distillation of water from one surface to

another, and this is not detected by a weighed lysimeter. The distillation is extremely local and thus has no significance in the water balance of large areas. The results presented by Long<sup>7</sup> suggest that the importance of distillation relative to deposition from the air above, diminishes as the height of the crop is greater. The amount of dew recorded by a weighed lysimeter would thus be dependent on the vegetation involved. It is probable that dew does not add water to a site in a hydrologically effective manner, since the water condensed on vegetation usually passes into the atmosphere very quickly.

**Conclusions.**—Since condensation is so subject to rain-gauge design, and because of the lack of relevance of dew-fall to many purposes for which precipitation measurements are used, it is suggested that Poncelet's conclusions should be adopted; that the measurement of dew-fall is the subject of completely different techniques, and dew collection in rain-gauges ought to be regarded as an error. It might be instructive to devise a gauge whose funnel is maintained at ambient air temperature to minimize this source of error, and thus discover the magnitude of the error in conventional designs.

#### REFERENCES

1. PONCELET, L.; The behaviour of rain-gauges. *Inst. mët. Belg., Brussels, Publ. Sér. A, No. 10*, 1959. (Translation by E. F. Lawes, East Africa Met. Dept., Nairobi, 1962.)
2. MONTEITH, J. L.; Dew. *Quart. J. R. met. Soc., London*, **83**, 1957, p. 323.
3. MONTEITH, J. L.; Dew. (Discussion). *Quart. J. R. met. Soc., London*, **84**, 1958, p. 180.
4. HIRST, J. M.; A simplified surface-wetness recorder. *Plant Path., London*, **6**, 1957, p. 57.
5. HARROLD, L. L. and DREIBELBIS, F. R.; Evaluation of agricultural hydrology by monolith lysimeters, 1944-1955. *Tech. Bull. U.S. Dep. Agric., Washington D.C.*, 1179, 1958.
6. HARROLD, L. L. and DREIBELBIS, F. R.; Errors in evaluations of dew amounts by the Coshocton lysimeters. *Bull. Int. Ass. sci. Hydrol., Gentbrugge, VII<sup>e</sup> Année, No. 3*, 1962, p. 73.
7. LONG, I. F.; Some observations on dew. *Met. Mag., London*, **87**, 1958, p. 161.

#### NOTES AND NEWS

##### **Agronomic implications of advection**

A very interesting lecture was given in the lecture theatre at the Headquarters of the Meteorological Office, Bracknell, on 26 February 1964, by Professor J. P. Hudson of the Department of Horticulture, Nottingham University. It was accompanied by many striking slides showing experimental work in progress.

The subject of the lecture concerned agronomic research in the Gezira area in the Sudan at the junction of the White and Blue Niles, with main emphasis on evaporation and irrigation problems of such crops as lucerne and cotton. The uncontrollable variability in yield of the latter crop was a worrying aspect, as shown, for example, in consecutive recent<sup>6</sup> years when cotton crops were respectively 155 per cent and 35 per cent of the long-term average. Although disease and pests can play an important part, weather must also be an essential factor in causing such variability.

An outline was given of the problem. The Gezira authority dictated absolutely what crops had to be grown on their scheme for two million acres, and where, in some 20,000 fields (or strips) which had been laid down with almost geometrical accuracy, each 300 yards  $\times$  1 mile in size—the experimenter's dream in many ways. Strips planted with irrigated crops such as cotton were irregularly alternated with fallow strips, so the ground presented a patchwork appearance.

Several main factors influenced the progress of the crop, such as the day-to-day weather, the pattern in which fields were arranged, and edge and zone effects. Edge effects related to the boundary between a transpiring crop and dry fallow land, and zone effects referred to the position of the crop within the whole cultivated area (roughly half the size of Wales).

The point was briefly made that contrary to popular belief weather variation did occur in the Sudan, and temperatures, humidities and wind strengths did not remain near average values, even if the sun was nearly always unobscured by cloud. Dry winds blew from the north fairly persistently however for much of the period of experimentation, and this gave rise to the clearly defined pattern of edge and zone effects already mentioned.

Instruments used to investigate the weather factor included thermometers in screens, evaporimeters and lysimeters. A hundred simple evaporimeters were specially made for this work and consisted of small aluminium dishes held in insulators, or moulded plastic containers of about the same size, and preliminary experiments confirmed that reproducible results could be achieved from these provided certain simple precautions were taken. Plate IV shows a typical piece of equipment as used in the field with the plastic-type evaporimeters mounted at five different heights up to 2 metres above ground, so that readings both above and in the crop could be taken.

Profiles of evaporation change were taken across stripped areas, and the results for two random dates are shown diagrammatically in Figure 1 which brings out the initial fall in the evaporation rate as soon as a crop was entered and the subsequent steadying to near a constant value after a penetration of about 100 yards. As soon as the crop was left, and dry fallow was entered, a sharp increase in evaporation occurred, almost to the pre-cotton level.

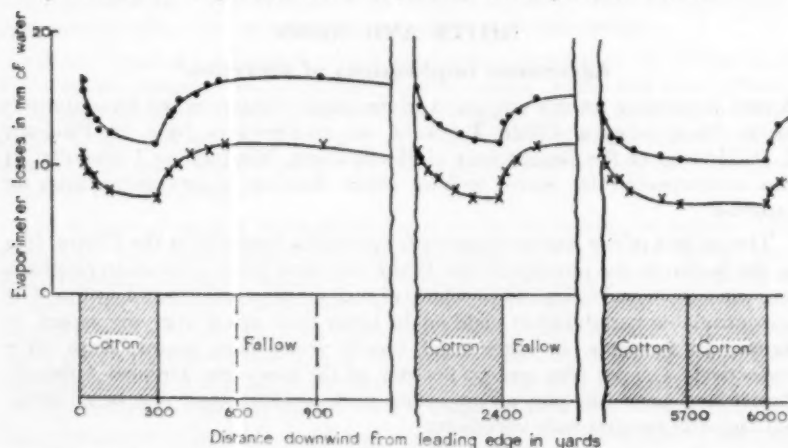


FIGURE 1—PROFILES OF EVAPORATION CHANGE TAKEN ACROSS A STRIPPED AREA ON TWO RANDOM DATES

—•— 31 December

—x— 19 December

Variation at different heights was brought out on another slide (Figure 2). This showed the rapid increase in evaporation rate above the surface in a

field of lucerne, with a point of inflexion at approximately the level of the crop top. The evaporation rate above open desert is also shown for comparison purposes.

Professor Hudson concluded by saying there were perhaps three main approaches to the assessment of water need: first-principle method such as Penman's, empirical methods of trial and error, and those based on simple instruments such as the evaporimeter used in the Gezira experiments.

An interesting discussion ensued. The Director-General thought temperature readings would be necessary to support evaporation measurements. Professor Hudson replied that these had been taken in some experiments though inevitably not in all. Subsequent discussion covered points such as the variability of crop yields being importantly due to disease as well as to frequency of irrigation need and arrangements of fields. Day-to-day evaporation varied by up to 30 per cent and weekly evaporation by 11 per cent in one period of 28 days. The zone effect was 1 per cent per mile downwind and the variation due to arrangement of fields could be 10 per cent, with half the reduction of evaporation taking place in the first 50 yards of crop across the leading edge of exposed fields. The

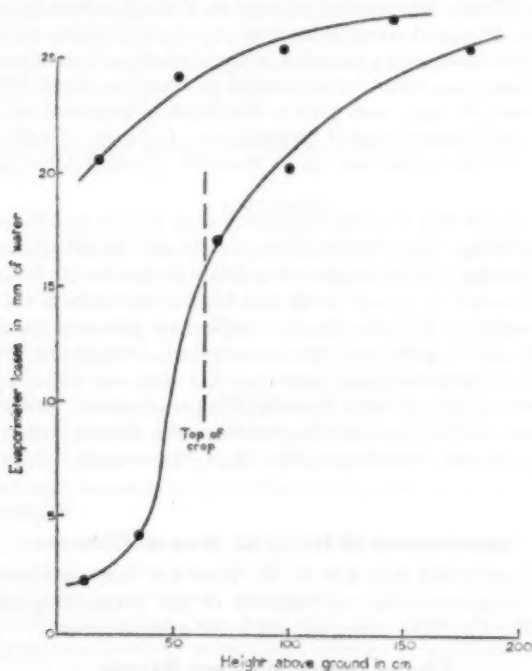


FIGURE 2—VARIATION OF EVAPORATION WITH HEIGHT ABOVE THE DESERT AND ABOVE A CROP OF LUCERNE

Upper curve—evaporation curve above desert; lower curve—evaporation curve 40 metres within a strip of lucerne.

point was made by Mr. L. P. Smith that the timing of irrigation might therefore be at least as important as edge effect and there would be advantage in irrigation on a need rather than a routine basis. In reply to a question, Professor Hudson

agreed that there would probably be real advantage in having all fields orientated north-south but that fairly definite proof would have to be given to the Gezira Board before the extensive replanning that would be involved could be contemplated.

The Director of Research brought the meeting to a close by thanking Professor Hudson very sincerely for the excellent and interesting account which he had just given—this was real practical applied meteorology, and it had been a pleasure to hear of such work in progress.

G. W. HURST

### **Meteorological Service of Canada**

#### **Resignation of Dr. P. D. McTaggart-Cowan, M.B.E.**

On 31 December 1963, Dr. P. D. McTaggart-Cowan resigned his position as Director of the Meteorological Service of Canada to become the first President of the Simon Fraser University in British Columbia.

Dr. McTaggart-Cowan is well known to many members of the Office staff, especially in relation to his work on transatlantic aviation meteorology. He was a Rhodes Scholar and studied physics at Oxford, where he also rowed in his college eight. In recent years he has been active in the sphere of international meteorology, first as an acting member of the Executive Committee in place of Dr. Andrew Thomson, whom he succeeded as Director of the Meteorological Service of Canada in 1959, and later as President of Regional Association IV. During the World Meteorological Organization Congress of 1963 he acted as Chairman of the Committee set up to consider administrative and financial matters.

There is no doubt that Pat McTaggart-Cowan will be greatly missed in the world of meteorology. His crisp incisive speech and unfailing courtesy made him a natural leader, both in technical and administrative problems. The new university is fortunate in having for its first head a man who is not only deeply interested in education but also has the intellectual gifts and physical stamina to make his ideas felt. Although, like many others, I regret the disappearance from international meteorological meetings of a wise and friendly companion, I recognize that in his new field he is fulfilling a life-time's ambition, and we may confidently expect that with his guidance the Simon Fraser University will become a notable element in the life of his country. We wish him all success.

O. G. SUTTON

#### **Appointment of Dr. T. G. How as Director**

We have been informed that Dr. T. G. How has been selected to succeed Dr. P. D. McTaggart-Cowan as Director of the Meteorological Service of Canada. We wish Dr. How every success in his appointment.

### **United States Weather Bureau**

#### **Retirement of Dr. F. W. Reichelderfer**

On 1 October 1963, Dr. Francis W. Reichelderfer retired from the post of Chief of the United States Weather Bureau, after holding office since 1939. In this period he not only guided the Bureau during years of spectacular change but also took a large part in international work. He was one of the 'founding fathers' of the World Meteorological Organization and as its President in the

critical initial period he, more than anyone else, gave it stability and a sense of purpose.

His record of achievement from the early days of naval aviation onwards is recorded in glowing terms in the journals of his country. Here I wish to add simply a personal word of admiration for a man whom I have known since 1948, both in America and elsewhere. The impression that remains is not only of wisdom and unruffled judgement but above all of unfailing kindness and courtesy. No one ever appealed to 'Reich' for help in vain, and he has never spared himself in his devotion to both the science and the profession of meteorology. His many friends in this country, both inside and outside the Office, will join with me in wishing him and Mrs. Reichelderfer many years of serene happiness in their well earned retirement.

O. G. SUTTON

### **New Chief of the United States Weather Bureau**

Dr. Robert M. White, who succeeded Dr. Reichelderfer as Chief of the United States Weather Bureau on 1 October 1963, was previously President of the Travelers Research Center, Hartford, Connecticut. He was born in Boston in 1923 and studied meteorology at the Massachusetts Institute of Technology, gaining the master's degree in 1949 and the doctorate in 1950. He also has been Chief of the Cambridge Research Center's Meteorological Development Laboratory.

We wish Dr. White all success in his new and onerous position.

### **REVIEWS**

*Weather and man*, World Meteorological Organization (WMO), Tech. Pap. No. 67. 9 in  $\times$  6 $\frac{1}{4}$  in, pp. 80, *illus.*, Geneva, WMO, 1964. Price: Sw.F. 2. (Also available from HMSO. Price: 3s. 6d.)

As acknowledged in an authoritative foreword by the Secretary-General of WMO the major part of the booklet—an exciting reply to the challenge of the United Nations Development Decade—has been written by Mr. L. P. Smith of the Meteorological Office. Mr. Smith has followed up his earlier "Weather and food" (which has already received world-wide praise from agriculturists) by a thought-provoking contribution to the problem of economic planning of the world's natural resources in the weather environments in which they perforce must be developed.

It was to be expected that the author would place agriculture at the forefront of the various subjects tackled. He has now, however, enlarged his field of interest by going on to discuss such topics as industry and trade, insurance and legal matters, transport (sea, land and air), the tourist industry, health, recreation, sports etc. in their relations to weather and climate.

Mr. Smith, writing in his usual lucid yet simple style (the booklet is one which tempts the reader to read it at one sitting), develops the idea that although aviators have for many years seriously considered the function of weather in their operations (from the viewpoint of safety of life as well as commercially) and have been meticulous in laying down their meteorological requirements which they have expected to be met, operators in other forms of activity have been slow to realize the effect of weather, have neglected to

formulate their needs and for the most part have failed even to discuss their problems with professional meteorologists able to help them. In his introduction the author indicates that weathermen have an essential part to play in natural development. "... the correct application of the science of meteorology is an investment in both personal and national fortunes ..."

Out-of-door activities obviously cannot escape the effect of weather and therefore the efficient manager should plan with both possibilities and probabilities in mind. For greatest economic gain, however, a complete pooling of ideas, operational and meteorological, is necessary.

In the chapter on Health, Mr. Smith hints at various effects of weather (including the psychological) and quotes a most interesting example of a chain reaction where ill health in South Australia was caused by early favourable monsoon rains in far off Queensland, the link being a rare migration of birds arising from an increase of breeding due to generous food supply.

Elsewhere the subject of meteorological disasters is discussed. Gales, floods and forest fires all receive attention, Encouraging figures are given of the reduction in hurricane disaster deaths in the U.S.A. where adequate warning services have been installed, However, we are warned that crying wolf may sometimes be expensive since it is estimated that a false hurricane warning may cost the city of Miami three-quarters of a million dollars a time.

Although Mr. Smith, as has already been mentioned, is largely responsible for the publication, a chapter on Water Resources has been contributed by Mr. Max Kohler of the U.S. Weather Bureau while suggestions made by the Director of the Israel Meteorological Service have also been incorporated.

It is a pity that the otherwise admirable selection of photographs in the booklet should be marred by the inclusion of an illustration of an operation rapidly becoming out of date—a pilot-balloon ascent—on the cover.

All meteorologists, especially those in the Public Service sector, should study this booklet and thus be stimulated to turn their thoughts to customers' needs. Perhaps more desirable, however, is that those in charge of industrial concerns of building and civil engineering projects, those planning future townships, health campaigns etc. should learn from its contents. "Weather and man" deserves the widest circulation in this field.

N. B. MARSHALL

*Grosswetterkunde und langfristige Witterungsvorhersage*, by Franz Baur. 10 $\frac{3}{4}$  in  $\times$  7 $\frac{1}{4}$  in, pp. 91, *illus.*, Akademische Verlagsgesellschaft, Frankfurt am Main, 1963. Price: 35 DM.

This book represents the proceedings of a seminar, held in Bad Homburg, Germany in October 1961, on large-scale meteorology and long-range weather forecasting. The occasion provided Franz Baur, unrivalled in his experience of the problems of long-range weather forecasting, with a platform from which to expound the results of his own and his close associates' researches.

Professor Baur's conclusions may be briefly summarized as follows. Methods of long-range forecasting which involve linear regression, periodicity, or symmetry points are doomed to failure. Real singularities of weather exist but are too unreliable to be useful. Large-scale weather patterns ("Grosswetterlagen"), involving the averaging of weather elements in space and time, must be recognized and the pattern of their occurrences, their relation to more local weather characteristics, their transitions and interrelations, etc. must be

studied. Changes in large-scale weather are, in no sense, the result of the coincidence of 'chance' events and they are therefore predictable. Complex but important relationships exist between solar activity and meteorological elements: solar faculae are a particularly valuable index in this respect.

The importance attached by Professor Baur to solar activity is made clear in the exposition of his method as applied to the then-approaching winter of 1961-62. It is of interest that at an earlier point he had dismissed as quite inadequate a forecasting technique capable of predicting three times out of four, the correct sign of the deviation from the mean. If, as is implied and as appears to be the case, Professor Baur's method achieves a degree of success substantially higher than this then those meteorologists—they include the reviewer—who have been sceptical about the existence of any proved connexion between solar activity and surface meteorology may have to revise their opinions. The difficulty here lies in applying an adequate significance test since the various relationships employed have been selected, from a large but indeterminate number of possibilities, because of their high proportionate success in past data. Fresh data with which to test the relationships accumulate only slowly.

In connexion with the controversial solar influence two further possibilities cannot be eliminated at present. First, the forecasts up to 1961 (not very numerous) may have enjoyed a large measure of good luck. Second, the success achieved may be a dependable measure of what is to be expected in the future but this success may result entirely from considered factors other than the solar connexions, despite the apparent emphasis placed on the latter.

The book contains an article, by another contributor, on connexions between tropospheric and stratospheric circulations. Some 10 pages of the volume are devoted to a discussion which took place during the final session. English abstracts of the (German) lectures and reports are given throughout.

D. H. MCINTOSH

### HONOUR

The following award was announced in the Birthday Honours List on 8 June 1964:

M.B.E.

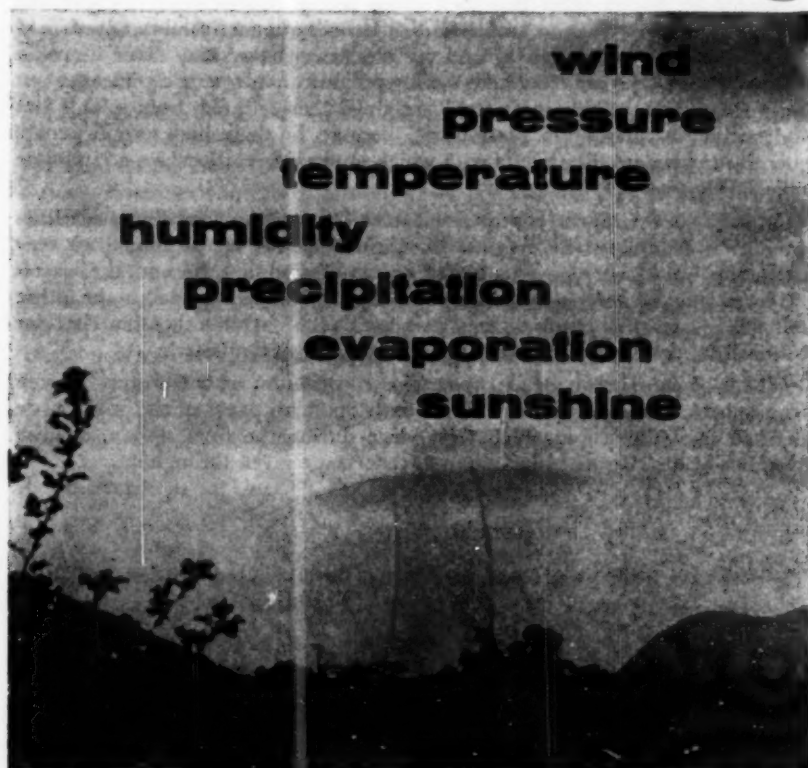
Mr. W. McKay, Senior Experimental Officer, Meteorological Office, Seychelles.

### OBITUARY

It is with deep regret that we record that on 31 May 1964, two firemen, Mr. R. Bain of Greenock and Mr. J. Kelly of Glasgow, lost their lives in a serious fire in the boiler room of the ocean weather ship *Weather Adviser*. Our sympathy is extended to the widows and their families.

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## CONTENTS

	<i>Page</i>
<b>Fluorescent particles and their use in studying air motion.</b>	
N. Thompson .. .. .	193
<b>Observations of noctilucent cloud near midwinter.</b> R. A.	
Hamilton .. .. .	201
<b>Delayed clearance of low cloud behind cold fronts at Manchester Airport.</b> L. Dent .. .. .	202
<b>Dew in rain-gauges.</b> E. R. C. Reynolds .. .. .	213
<b>Notes and news</b>	
Agronomic implications of advection .. .. .	217
Resignation of Dr. P. D. McTaggart-Cowan, M.B.E. .. .. .	220
Appointment of Dr. T. G. How as Director .. .. .	220
Retirement of Dr. F. W. Reichelderfer .. .. .	221
New Chief of the United States Weather Bureau .. .. .	221
<b>Reviews</b>	
Weather and man. World Meteorological Organization Tech. Pap. No. 67. <i>N. B. Marshall</i> .. .. .	221
Graswetterkunde und langfristige Witterungsvorhersage. Franz Baur. <i>D. H. McIntosh</i> .. .. .	222
<b>Honour</b> .. .. .	223
<b>Obituary</b> .. .. .	223

## NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire, and marked "for Meteorological Magazine."

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

All inquiries relating to the insertion of advertisements in the Meteorological Magazine should be addressed to the Director of Publications, H.M. Stationery Office, Atlantic House, Holborn Viaduct, London E.C.1. (Telephone: CITY 9876, extn 147).

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